The dusty SF history of high-z galaxies, modelling tools and future prospects

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Abstract. We summarize recent advances in the determination of the cosmic history of star formation and other properties of high-z galaxies, and the relevance of this information in our understanding of the formation of structures. We emphasize the importance of dust reprocessing in the high–z universe, as demonstrated in particular by IR and sub-mm data. This demand a panchromatic approach to observations and suitable modelling tools. We spend also some words on expectations from future instruments.

1. Introduction

In the last few years, a huge number of studies of the high-z universe have been devoted to the determination of the cosmic history of star formation $SFR(z)$. The main motivation for these efforts is that baryons are the only observational tracers of the evolution of large scale structures, which are believed to be driven by the gravitational collapse of dark matter (DM). The determination of $SFR(z)$ can in principle help to discriminate between different proposed scenarios for the formation and evolution of galaxies.

A fundamental issue connected to the determination of $SFR(z)$ is the fraction of light produced by stars which has been reprocessed by dust into IR photons. We know that in the local universe surveyed by IRAS this fraction is $\sim 30\%$. Though this is a significative percentage, it is not dramatic, in the sense that if the same were true also at high–z, optical–UV observations would determine $SFR(z)$ with a small uncertainty. But IRAS observations demonstrated also that dust reprocessing in local galaxies is a strong increasing function of their star formation activity, and can't be reliably determined by UV and optical data alone. This is vividly illustrated for instance by figure 2 of Sanders & Mirabel (1996), which shows that infrared-selected galaxies range over 3 orders of magnitude in L_{IR}, while the optical luminosity changes only by a factor of 3-4, with minor differences in the shape of the optical-UV SED. A more model dependent example of this is shown in Fig. 1. The possibility to measure the amount of dust hidden

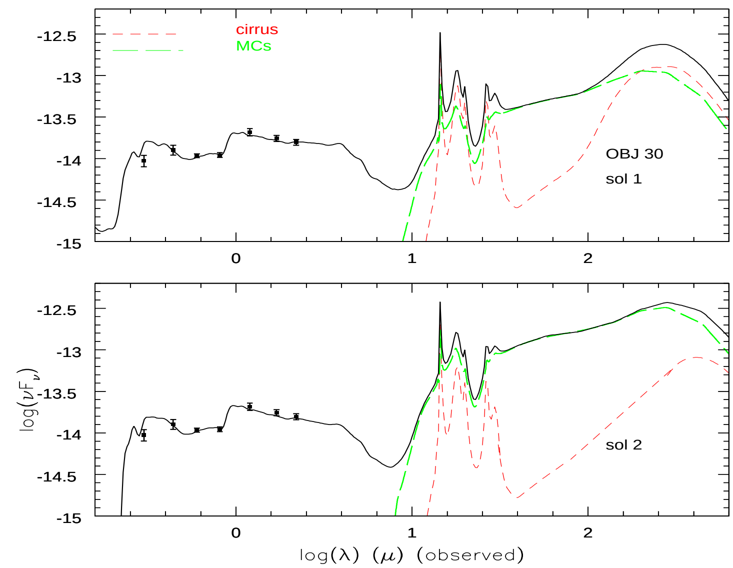

Figure 1. The observed optical-NIR SED of a late–type galaxy in HDF-N at z=1.3 is reproduced with plausible models differing by a factor 3 in SFR. Adapted from Rodighiero et al. (2000).

SF from the optical-UV SED has been discussed quite a lot, for instance using the Meuer's correlation between the UV spectral index and the ratio L_{UV}/L_{IR}. This relationship is found to be quite narrow for some classes of starburst galaxies, however it has recently been shown that it does not hold for the most luminous starburst galaxies at low redshift (Meuer et al. 1999; Meuer et al. 2000; see also Panuzzo et al, these proceedings).

It is therefore quite natural to suspect that in the younger, more active universe an higher fraction of star luminosity was reprocessed by dust, and that in this situation the global SF activity can be reliably measured only by means of FIR and sub-mm data.

2. The dusty SF history of galaxies

Indeed, several pieces of evidence in the paste few years have shown that *most of the SF in the high–z universe is dust obscured or dimmed to a substantial degree:*

(1) The discovery of a cosmic far-IR/sub-mm background by the COBE satellite (Puget et al. 1996; Fixsen et al. 1998; Hauser et al. 1998),

whose energy density, which is at least a factor 2 larger than the optical-UV one, indicates that a large fraction of the energy radiated by stars over the history of the universe has been reprocessed by dust.

(2) The SCUBA detection of a population of bright 850μm sources. Surveys at around 1 mm are very effective in discovering high-z dust enshrouded star formation, due to the steep increase of the expected SED of dusty star forming galaxies shortward this wavelength (see Silva et al. in these proceedings). Indeed, the resulting strong positive K correction is able to counterbalance the cosmological dimming with increasing z for $1 \lesssim z \lesssim 8$ (details depend of course on the precise λ of the survey and on the cosmological parameters). As a result, the expected mm flux of a given luminosity source remains almost constant in this redshift range. Since the comoving cosmic volume element increases up to $z \sim 2$, the conclusion is that mm or sub-mm surveys are strongly biased in favor of dusty high redshift objects.

In the last few years this fact has been exploited in particular by surveys at 850μm performed with the SCUBA camera at JCMT. These surveys led to the discovery of a population of sub-mm sources at high redshift ($z \gtrsim 1.5$), whose luminosities, if powered by star formation in dust-enshrouded galaxies, imply very large star formation rates ($\gtrsim 10^2 M_\odot \mathrm{yr}^{-1}$), and a total star formation density probably greater than that inferred from the UV luminosities of the Lyman-break galaxies (Smail et al. 1997; Hughes et al. 1998). Also, this bright population is originating a significant fraction of the IR background (eg. Blain 2000)

(3) The ISO detection of a population of strong IR sources; 15 μm ISOCAM (Oliver et al 1997) and 175 μm ISOPHOT surveys (Kawara et al 1998; Puget et al 1999) show a population of actively star forming galaxies at $0.4 < z < 1.3$, mostly disk/interacting galaxies with K typical of a L* galaxy. This population boosts the cosmic star formation density by a factor ~ 3 with respect to that estimated in the optical from the CFRS in the same redshift range.

For (1) and (2), there is the caveat that the contribution from dust-enshrouded AGNs to the sub-mm counts and background is currently uncertain, but probably the AGNs do not dominate (e.g. Granato, Danese & Franceschini 1997).

A summary of the present status of the determination of $SFR(z)$ is given for instance by figure 17 of Genzel & Cesarsky (2000). The main point is that while a few years ago it was claimed, based on optical

observations, that this function had a peak at $z \simeq 1$ and declined at higher redshifts, it is now clear instead that $SFR(z)$ steeply increases from $z = 0$ to $z = 1$, but than stays essentially flat to at least $z \simeq 4$.

3. Interpretative tools

These observations should be framed in the hierarchical structure formation paradigm. In this scenario, structures result from the gravitational amplification of small, primordial density fluctuations, possibly quantum ripples boosted to macroscopic scales by inflation. The subsequent formation and merging of DM haloes is driven by gravitation and fully determined by the initial density fluctuations and by the cosmology.

While the simulation of the behaviour of the DM component of the universe is a relatively simple task, a much more difficult problem is to predict the evolution of the baryonic component, subject to a much more complex physics. As a matter of fact, to date it is not possible to follow by direct numerical simulations these processes with the dynamical range relevant for galaxy formation. The most employed technique is instead that of semi-analytical models, in which simplified analytical descriptions of baryon processes (e.g. gas cooling and collapse, star formation, supernovae feedback and galaxy merging) are adopted (see Cole et al. 2000). The predicted SF histories are then combined with stellar population models including dust reprocessing, in order to predict galaxy observational properties.

Present semi-analytical models compare favorably with most observations, including many IR constraints (Granato et al 2000 and references therein; Silva 1999) but are seriously challenged by sub-mm counts, which turn out to be underpredicted by about one order of magnitude (Fig. 2). This, coupled with the fact that these models are instead able to reproduce the observed background from the FUV to the sub-mm, leads to the conclusion that the main problem is that they spread the total SF activity in too many but too faint episodes, with respect to what sub-mm counts indicate. To fix this problem, the simplified prescriptions used in semi-analytical models to describe the behavior of baryons in DM halos need some substantial revision, on which work is in progress (Lacey et al, in preparation). It is clear that, in some sense, semi-analytical models, based on the hierarchical clustering paradigm, should be modified in such a way that the formation of a subset of galaxies resemble the prediction of the so called "monolithic scenario" (Eggen, Lynden-Bell & Sandage, 1962; Larson, 1975)

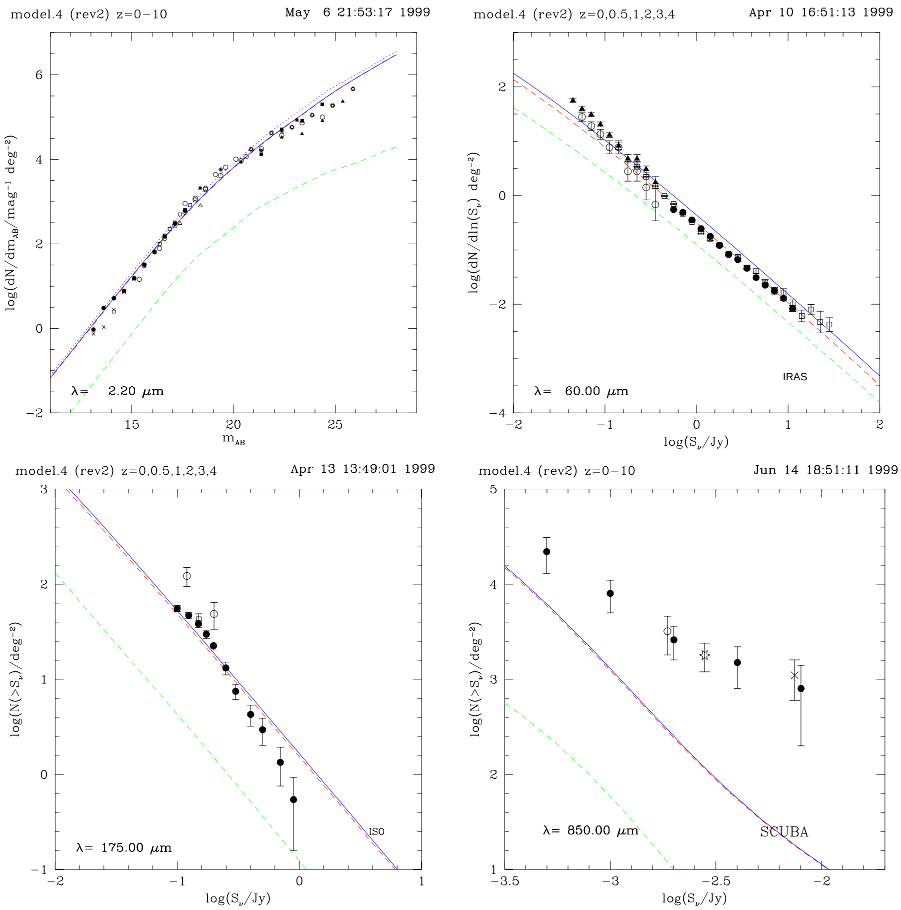

Figure 2. Number counts at 2.2, 60, 175 and 850 μm. Standard semi-analytical models fail to reproduce the 850μm SCUBA counts. Some substantial revision of the prescriptions used for star formation at high redshift seems unavoidable (Silva 1999; see also Lacey et al 2001, in preparation)

Further indications of this can be gained taking advantage of the observational evidence suggesting that QSOs did shine in the core of early-type protogalaxies, during their main episode of star formation. Granato et al (2001) used this information to derive the formation rate of spheroids as a function of redshift, essentially by means of a deconvolution of the rather well known evolution of the QSO luminosity function. Then they used GRASIL (Silva et al 1998) to predict their SED evolution in the FIR sub-mm region. In this way they have shown that SCUBA counts are well reproduced by early-type protogalaxies (Fig. 3), in particular if the active formation phase was quicker in more

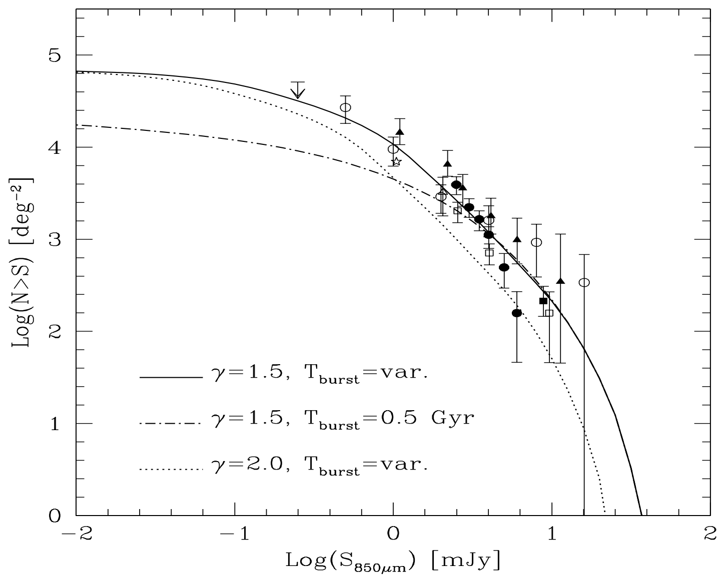

Figure 3. The formation rate for spheroids derived from the QSO luminosity function evolution, coupled with plausible assumption for their SED evolution can easily reproduce the 850μm SCUBA counts. Adapted from Granato et al. (2001).

massive objects, as suggested by chemical enrichment studies (Thomas, Greggio & Bender 1999 and references therein).

4. Prospects for the future

Although mm observations have had a strong impact on models for the formation and evolution of galaxies in the past few years, and are leading to a major revision of them, a systematic study of the high-z universe is almost impossible with present instruments, which are limited by a small accessible area and poor resolution. As a consequence, up to now relatively few objects have been detected, and their optical identification, which is at present a necessary step to obtain a spectroscopic redshift, is difficult. Also, the confusion limits at faint fluxes are severe: the confusion noise may be important at $\lesssim 2$ mJy for SCUBA (Blain 2000).

In summary, we have now only $\sim 10^2$ sub-mm selected sources mostly without a key information: a reliable redshift. For most of the sources we have only "photometric" redshifts (or lower limits), based on ratios of fluxes in two different sub-mm bands or on sub-mm to radio ratios.

The detection rates for surveys to be performed with future IR and submillimetric facilities (e.g. SIRTF, LMT, ALMA, Herschel-FIRST) are expected to increase by orders of magnitude with respect to present ones (e.g. figure 4 in Blain 1999). A fundamental point is that these large samples could be of little use to further constrain the history of star formation in the universe, unless good estimates of the redshits will be available. On one hand, it will be possible to combine information coming from surveys at different wavelengths, if properly planned, to estimate photometric redshifts (see also Silva et al contribution to these proceedings). On the other hand the development of the "redshift machine" at LMT and ALMA, based on an order of magnitude increase of the bandwidth of sub-mm detectors, will allow to determine the spectroscopic redshift of the sources directly from CO transitions, without the need of the optical identification (see Carrasco contribution).

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